R2019_810P2 *[217 marks]*

The ratio $\frac{\text{distance of Mars from the Sun}}{\text{distance of Earth from the Sun}} = 1.5$.

1a. Show that the intensity of solar radiation at the orbit of Mars is about 600 W m^{-2}. *[2 marks]*

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1b. Determine, in K, the mean surface temperature of Mars. Assume that Mars acts as a black body. *[2 marks]*

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1c. The atmosphere of Mars is composed mainly of carbon dioxide and has a pressure less than 1 % of that on the Earth. Outline why the greenhouse effect is not significant on Mars. *[2 marks]*

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2a. State how the density of a nucleus varies with the number of nucleons in the nucleus. *[1 mark]*

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2b. Show that the nuclear radius of phosphorus-31 ($^{31}_{15}\mathrm{P}$) is about 4 fm. *[1 mark]*

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$^{32}_{15}\mathrm{P}$ is formed when a nucleus of deuterium ($^{2}_{1}\mathrm{H}$) collides with a nucleus of $^{31}_{15}\mathrm{P}$. The radius of a deuterium nucleus is 1.5 fm.

2c. State the maximum distance between the centres of the nuclei for which the production of $^{32}_{15}\mathrm{P}$ is likely to occur. *[1 mark]*

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2d. Determine, in J, the minimum initial kinetic energy that the deuterium nucleus must have in order to produce $^{32}_{15}\mathrm{P}$. Assume that the phosphorus nucleus is stationary throughout the interaction and that only electrostatic forces act. *[2 marks]*

2e. $^{32}_{15}\mathrm{P}$ undergoes beta-minus (β^-) decay. Explain why the energy gained by the emitted beta particles in this decay is not the same for every beta particle. *[2 marks]*

2f. State what is meant by decay constant. *[2 marks]*

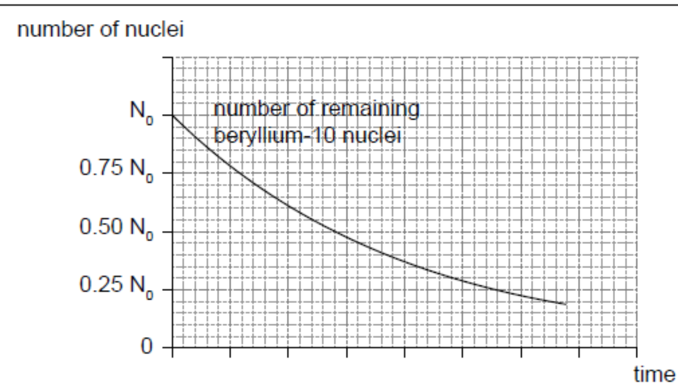
2g. In a fresh pure sample of $^{32}_{15}\mathrm{P}$ the activity of the sample is 24 Bq. After one week the activity has become 17 Bq. Calculate, in s^{-1}, the decay constant of $^{32}_{15}\mathrm{P}$. *[3 marks]*

The radioactive nuclide beryllium-10 (Be-10) undergoes beta minus (β–) decay to form a stable boron (B) nuclide.

3a. Identify the missing information for this decay. *[1 mark]*

$$^{10}_{\square}\mathrm{Be} \rightarrow {}^{\square}_{5}\mathrm{B} + \beta + \bar{\upsilon}$$

The initial number of nuclei in a pure sample of beryllium-10 is N_0. The graph shows how the number of remaining **beryllium** nuclei in the sample varies with time.



3b. On the graph, sketch how the number of **boron** nuclei in the sample varies with time. *[2 marks]*

3c. After 4.3×10^6 years, *[3 marks]*

$$\frac{\text{number of produced boron nuclei}}{\text{number of remaining beryllium nuclei}} = 7.$$

Show that the half-life of beryllium-10 is 1.4×10^6 years.

3d. Beryllium-10 is used to investigate ice samples from Antarctica. A sample of ice initially contains 7.6×10^{11} atoms of beryllium-10. State the number of remaining beryllium-10 nuclei in the sample after 2.8×10^6 years. *[1 mark]*

An ice sample is moved to a laboratory for analysis. The temperature of the sample is –20 °C.

3e. State what is meant by thermal radiation. *[1 mark]*

3f. Discuss how the frequency of the radiation emitted by a black body can be used to estimate the temperature of the body. *[2 marks]*

3g. Calculate the peak wavelength in the intensity of the radiation emitted by the ice sample. *[2 marks]*

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3h. Derive the units of intensity in terms of fundamental SI units. *[2 marks]*

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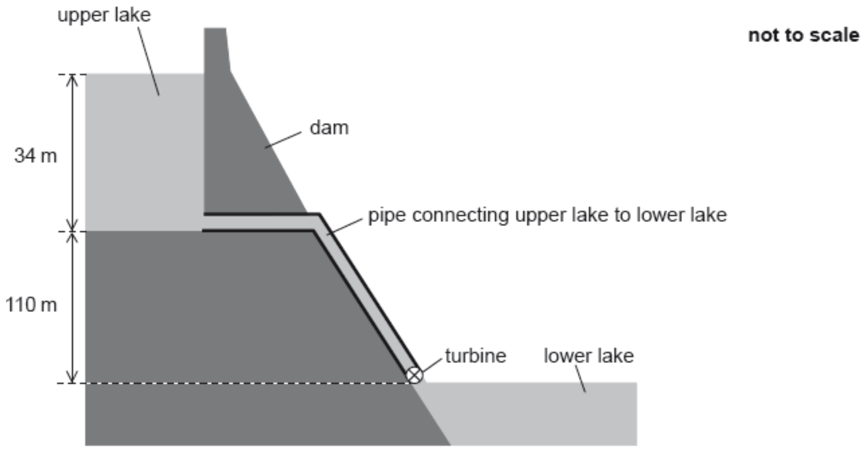
In a pumped storage hydroelectric system, water is stored in a dam of depth 34 m.



The water leaving the upper lake descends a vertical distance of 110 m and turns the turbine of a generator before exiting into the lower lake.

Water flows out of the upper lake at a rate of 1.2×10^{5} m^3 per minute. The density of water is 1.0×10^3 kg m^{-3}.

4a. Estimate the specific energy of water in this storage system, giving an appropriate unit for your answer. *[2 marks]*

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4b. Show that the average rate at which the gravitational potential energy of the water decreases is 2.5 GW. *[3 marks]*

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4c. The storage system produces 1.8 GW of electrical power. Determine the overall efficiency of the storage system. *[1 mark]*

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4d. After the upper lake is emptied it must be refilled with water from the lower lake and this requires energy. Suggest how the operators of this storage system can still make a profit. *[1 mark]*

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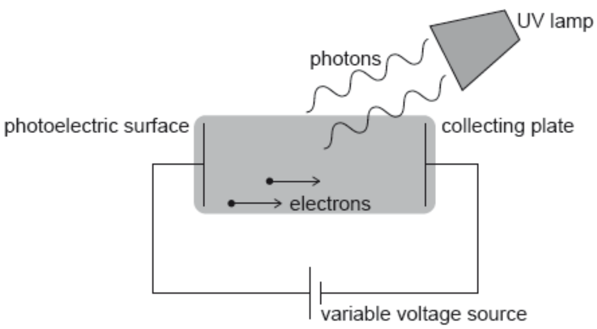
Hydrogen atoms in an ultraviolet (UV) lamp make transitions from the first excited state to the ground state. Photons are emitted and are incident on a photoelectric surface as shown.



5a. Show that the energy of photons from the UV lamp is about 10 eV. *[2 marks]*

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The photons cause the emission of electrons from the photoelectric surface. The work function of the photoelectric surface is 5.1 eV.

5b. Calculate, in J, the maximum kinetic energy of the emitted electrons. *[2 marks]*

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5c. Suggest, with reference to conservation of energy, how the variable voltage source can be used to stop all emitted electrons from reaching the collecting plate. *[2 marks]*

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5d. The variable voltage can be adjusted so that no electrons reach the collecting plate. Write down the minimum value of the voltage for which no electrons reach the collecting plate. *[1 mark]*

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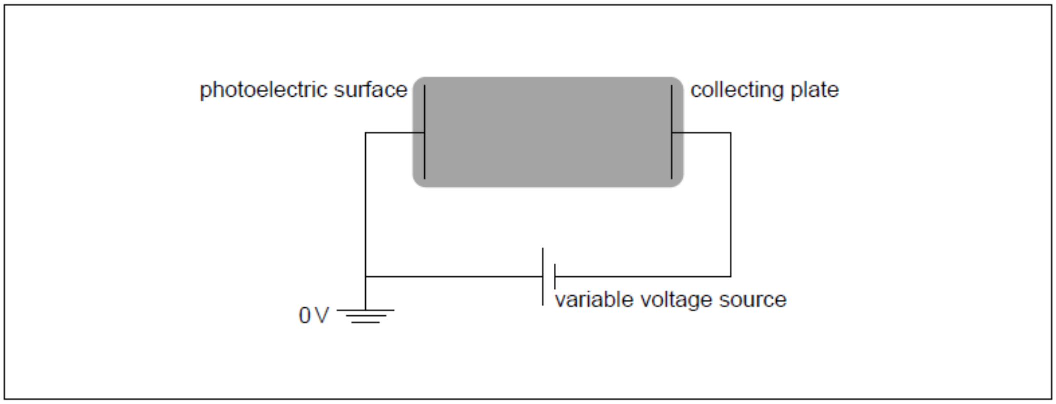
The electric potential of the photoelectric surface is 0 V. The variable voltage is adjusted so that the collecting plate is at –1.2 V.



5e. On the diagram, draw and label the equipotential lines at –0.4 V and –0.8 V. *[2 marks]*

5f. An electron is emitted from the photoelectric surface with kinetic energy 2.1 eV. Calculate the speed of the electron at the collecting plate. *[2 marks]*

A planet has radius *R*. At a distance *h* above the surface of the planet the gravitational field strength is *g* and the gravitational potential is *V*.

6a. State what is meant by gravitational field strength. *[1 mark]*

6b. Show that $V = -g(R + h)$. *[2 marks]*

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6c. Draw a graph, on the axes, to show the variation of the gravitational potential V of the planet with height h above the surface of the planet. *[2 marks]*

6d. A planet has a radius of 3.1×10^{6} m. At a point P a distance 2.4×10^{7} m above the surface of the planet the gravitational field strength is 2.2 N kg^{-1}. Calculate the gravitational potential at point P, include an appropriate unit for your answer. *[1 mark]*

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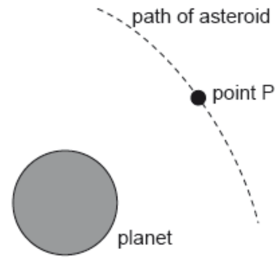
6e. The diagram shows the path of an asteroid as it moves past the planet. *[3 marks]*



When the asteroid was far away from the planet it had negligible speed. Estimate the speed of the asteroid at point P as defined in (b).

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6f. The mass of the asteroid is 6.2×10^{12} kg. Calculate the gravitational force experienced by the **planet** when the asteroid is at point P. *[2 marks]*

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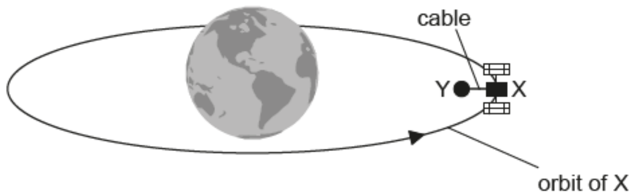
There is a proposal to power a space satellite X as it orbits the Earth. In this model, X is connected by an electronically-conducting cable to another smaller satellite Y.



not to scale

7a. Satellite X orbits 6600 km from the centre of the Earth. *[2 marks]*

Mass of the Earth = 6.0×10^{24} kg

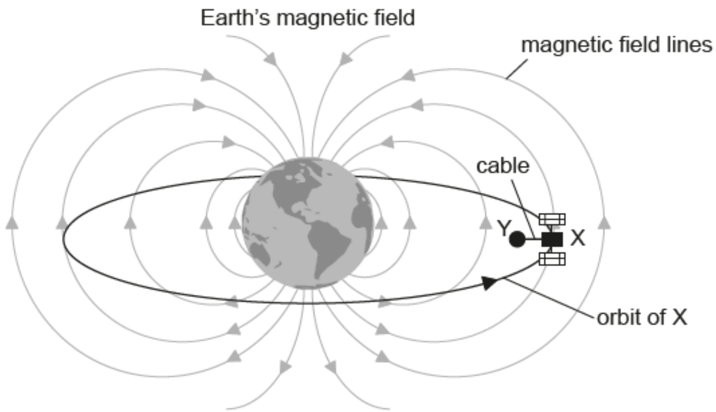
Show that the orbital speed of satellite X is about 8 km s^{-1}.

Satellite Y orbits closer to the centre of Earth than satellite X. Outline why

7b. the orbital times for X and Y are different. *[1 mark]*

7c. satellite Y requires a propulsion system. *[2 marks]*

7d. The cable between the satellites cuts the magnetic field lines of the Earth at right angles. *[3 marks]*



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Explain why satellite X becomes positively charged.

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7e. Satellite X must release ions into the space between the satellites. Explain why the current in the cable will become zero unless there is a method for transferring charge from X to Y. *[3 marks]*

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7f. The magnetic field strength of the Earth is 31 μT at the orbital radius of the satellites. The cable is 15 km in length. Calculate the emf induced in the cable. *[2 marks]*

The cable acts as a spring. Satellite Y has a mass *m* of 3.5×10^2 kg. Under certain circumstances, satellite Y will perform simple harmonic motion (SHM) with a period *T* of 5.2 s.

7g. Estimate the value of *k* in the following expression. *[3 marks]*

$T = 2\pi\sqrt{\frac{m}{k}}$

Give an appropriate unit for your answer. Ignore the mass of the cable and any oscillation of satellite X.

7h. Describe the energy changes in the satellite Y-cable system during one cycle of the oscillation. *[2 marks]*

Two renewable energy sources are solar and wind.

8a. Describe the difference between photovoltaic cells and solar heating panels. *[1 mark]*

8b. A solar farm is made up of photovoltaic cells of area 25 000 m^2. The average solar intensity falling on the farm is 240 W m^{-2} and the average power output of the farm is 1.6 MW. Calculate the efficiency of the photovoltaic cells. *[2 marks]*

An alternative generation method is the use of wind turbines.

The following data are available:

Length of turbine blade = 17 m
Density of air = 1.3 kg m^{-3}
Average wind speed = 7.5 m s^{-1}

8c. Determine the minimum number of turbines needed to generate the same power as the solar farm. *[3 marks]*

8d. Explain **two** reasons why the number of turbines required is likely to be greater than your answer to (c)(i). *[2 marks]*

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9a. Outline the conditions necessary for simple harmonic motion (SHM) to occur. *[2 marks]*

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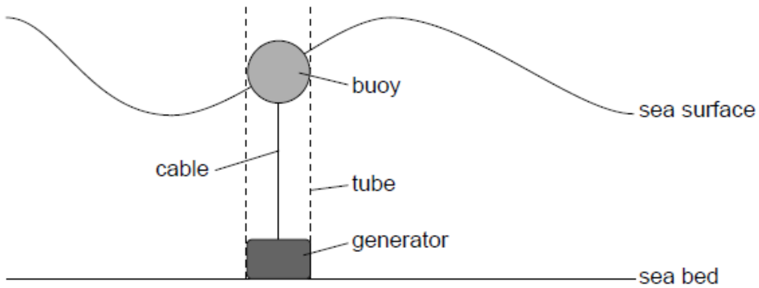
A buoy, floating in a vertical tube, generates energy from the movement of water waves on the surface of the sea. When the buoy moves up, a cable turns a generator on the sea bed producing power. When the buoy moves down, the cable is wound in by a mechanism in the generator and no power is produced.



The motion of the buoy can be assumed to be simple harmonic.

9b. A wave of amplitude 4.3 m and wavelength 35 m, moves with a speed of 3.4 m s^{-1}. *[3 marks]*
Calculate the maximum vertical speed of the buoy.

9c. Sketch a graph to show the variation with time of the generator output power. Label the time axis with a suitable scale. *[2 marks]*

Water can be used in other ways to generate energy.

9d. Outline, with reference to energy changes, the operation of a pumped storage hydroelectric system. *[2 marks]*

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9e. The water in a particular pumped storage hydroelectric system falls a vertical distance of 270 m to the turbines. Calculate the speed at which water arrives at the turbines. Assume that there is no energy loss in the system. *[2 marks]*

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9f. The hydroelectric system has four 250 MW generators. Determine the maximum time for which the hydroelectric system can maintain full output when a mass of 1.5×10^{10} kg of water passes through the turbines. *[2 marks]*

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9g. Not all the stored energy can be retrieved because of energy losses in the system. Explain **two** such losses. *[2 marks]*

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The gravitational potential due to the Sun at its surface is -1.9×10^{11} J kg^{-1}. The following data are available.

Mass of Earth	$= 6.0 \times 10^{24}$ kg
Distance from Earth to Sun	$= 1.5 \times 10^{11}$ m
Radius of Sun	$= 7.0 \times 10^{8}$ m

10a. Outline why the gravitational potential is negative. *[2 marks]*

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10b. The gravitational potential due to the Sun at a distance *r* from its centre is V_S. Show that *[1 mark]*

rV_S = constant.

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10c. Calculate the gravitational potential energy of the Earth in its orbit around the Sun. Give your answer to an appropriate number of significant figures. *[2 marks]*

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10d. Calculate the total energy of the Earth in its orbit. *[2 marks]*

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10e. An asteroid strikes the Earth and causes the orbital speed of the Earth to suddenly decrease. Suggest the ways in which the orbit of the Earth will change. *[2 marks]*

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10f. Outline, in terms of the force acting on it, why the Earth remains in a circular orbit around the Sun. *[2 marks]*

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The following data are available for a natural gas power station that has a high efficiency.

Rate of consumption of natural gas	= 14.6 kg s^{-1}
Specific energy of natural gas	= 55.5 MJ kg^{-1}
Efficiency of electrical power generation	= 59.0 %
Mass of CO_2 generated per kg of natural gas	= 2.75 kg
One year	= 3.16×10^7 s

11a. Calculate, with a suitable unit, the electrical power output of the power station. *[1 mark]*

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11b. Calculate the mass of CO_2 generated in a year assuming the power station operates continuously. *[1 mark]*

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11c. Explain, using your answer to (b), why countries are being asked to decrease their dependence on fossil fuels. *[2 marks]*

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11d. Describe, in terms of energy transfers, how thermal energy of the burning gas becomes electrical energy. *[2 marks]*

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12a. Explain what is meant by the gravitational potential at the surface of a planet. *[2 marks]*

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12b. An unpowered projectile is fired vertically upwards into deep space from the surface of planet Venus. Assume that the gravitational effects of the Sun and the other planets are negligible. *[5 marks]*

The following data are available.

Mass of Venus = 4.87×10^{24} kg Radius of Venus = 6.05×10^{6} m Mass of projectile = 3.50×10^{3} kg
Initial speed of projectile = $1.10\times$escape speed

(i) Determine the initial kinetic energy of the projectile.

(ii) Describe the subsequent motion of the projectile until it is effectively beyond the gravitational field of Venus.

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The Sun has a radius of 7.0×10^{8}m and is a distance 1.5×10^{11} m from Earth. The surface temperature of the Sun is 5800 K.

13a. Show that the intensity of the solar radiation incident on the upper atmosphere of the Earth is approximately $1400 Wm^{-2}$. *[2 marks]*

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13b. The albedo of the atmosphere is 0.30. Deduce that the average intensity over the entire surface of the Earth is $245 Wm^{-2}$. *[2 marks]*

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13c. Estimate the average surface temperature of the Earth. *[2 marks]*

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14. The average surface temperature of the Earth is actually 288 K. *[2 marks]*

Suggest how the greenhouse effect helps explain the difference between the temperature estimated in (c) and the actual temperature of the Earth.

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This question is in **two** parts. **Part 1** is about energy resources. **Part 2** is about thermal physics.

Part 1 Energy resources

Electricity can be generated using nuclear fission, by burning fossil fuels or using pump storage hydroelectric schemes.

15a. Outline which of the three generation methods above is renewable. *[2 marks]*

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In a nuclear reactor, outline the purpose of the

15b. heat exchanger. *[1 mark]*

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15c. moderator. *[2 marks]*

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Fission of one uranium-235 nucleus releases 203 MeV.

15d. Determine the maximum amount of energy, in joule, released by 1.0 g of uranium-235 as a result of fission. *[3 marks]*

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15e. Describe the main principles of the operation of a pump storage hydroelectric scheme. *[3 marks]*

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15f. A hydroelectric scheme has an efficiency of 92%. Water stored in the dam falls through an average height of 57 m. Determine the rate of flow of water, in $\mathrm{kg\,s^{-1}}$, required to generate an electrical output power of 4.5 MW. *[3 marks]*

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This question is in **two** parts. **Part 1** is about energy resources. **Part 2** is about thermal physics.

Part 2 Thermal physics

15g. Distinguish between specific heat capacity and specific latent heat. *[2 marks]*

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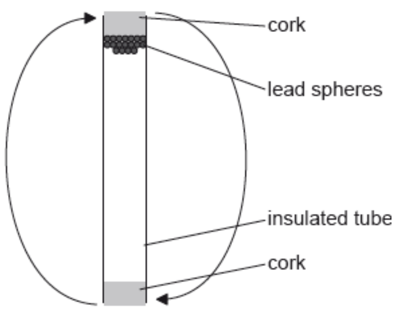
A mass of 0.22 kg of lead spheres is placed in a well-insulated tube. The tube is turned upside down several times so that the spheres fall through an average height of 0.45 m each time the tube is turned. The temperature of the spheres is found to increase by 8 °C.



15h. Discuss the changes to the energy of the lead spheres. *[2 marks]*

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15i. The specific heat capacity of lead is $1.3 \times 10^2\ \mathrm{J\,kg^{-1}K^{-1}}$. Deduce the number of times that the tube is turned upside down. *[4 marks]*

This question is about energy sources.

A small island is situated in the Arctic. The islanders require an electricity supply but have no fossil fuels on the island. It is suggested that wind generators should be used in combination with power stations using either oil or nuclear fuel.

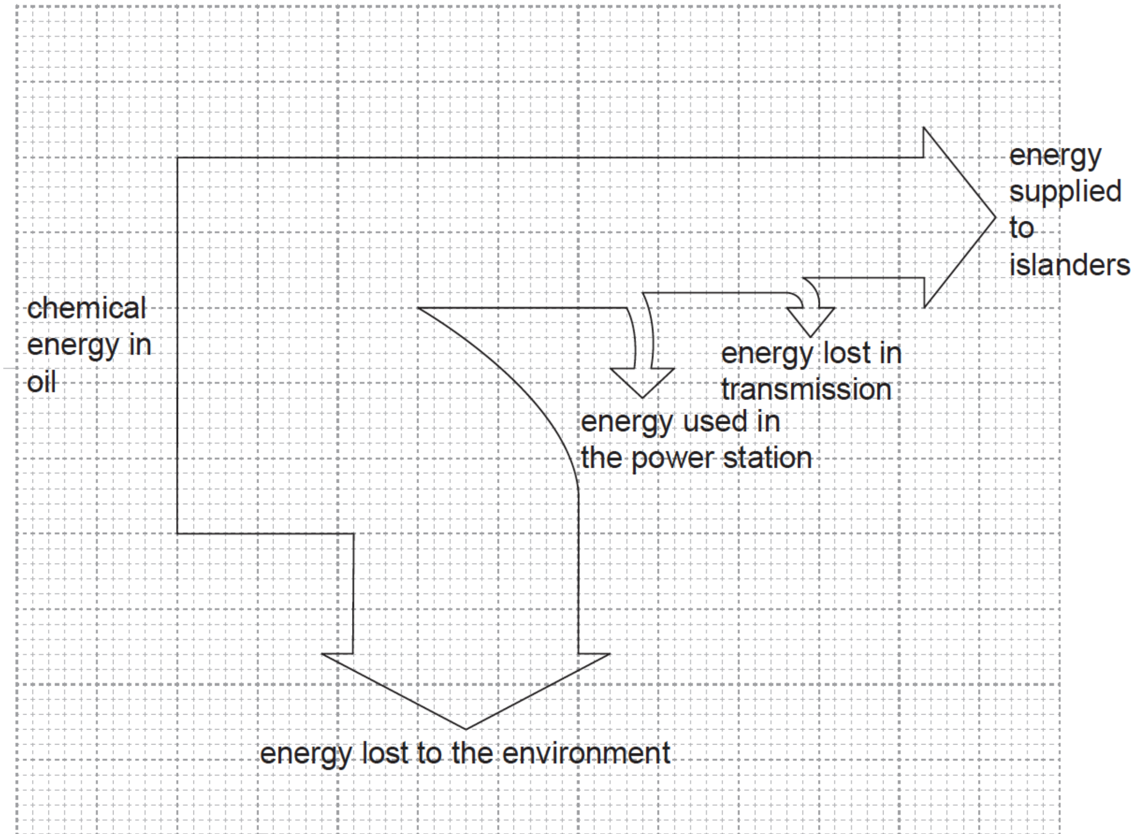
16a. Suggest the conditions that would make use of wind generators in combination with either oil or nuclear fuel suitable for the islanders. *[3 marks]*

16b. Conventional horizontal-axis wind generators have blades of length 4.7m. The average wind speed on the island is 7.0ms^{-1} and the average air density is 1.29kgm^{-3}. *[5 marks]*

(i) Deduce the total energy, in GJ, generated by the wind generators in one year.

(ii) Explain why less energy can actually be generated by the wind generators than the value you deduced in (b)(i).

16c. The energy flow diagram (Sankey diagram) below is for an oil-fired power station that the islanders might use. *[4 marks]*



(i) Determine the efficiency of the power station.

(ii) Explain why energy is wasted in the power station.

(iii) The Sankey diagram in (c) indicates that some energy is lost in transmission. Explain how this loss occurs.

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16d. The emissions from the oil-fired power station in (c) are likely to increase global warming by the enhanced greenhouse effect. *[3 marks]*

Outline the mechanism by which greenhouse gases contribute to global warming.

16e. Nuclear fuel must be enriched before it can be used. Outline why fuel enrichment is needed. *[2 marks]*

16f. The nuclear equation below shows one of the possible fission reactions in a nuclear reactor. *[3 marks]*

$$\left({}^{1}_{0}\mathrm{n} + {}^{\dots}_{92}\mathrm{U} \rightarrow {}^{92}_{\dots}\mathrm{Kr} + {}^{141}_{56}\mathrm{Ba} + \dots {}^{1}_{0}\mathrm{n}\right)$$

Identify the missing numbers in the equation.

16g. A nuclear reactor requires both control rods and a moderator to operate. Outline, with reference to neutrons, **one** similarity and **two** differences in the function of each of these components. *[3 marks]*

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This question is in two parts. **Part 1** is about renewable energy. **Part 2** is about nuclear energy and radioactivity.

Part 1 Renewable energy

A small coastal community decides to use a wind farm consisting of five identical wind turbines to generate part of its energy. At the proposed site, the average wind speed is $8.5 ms^{-1}$ and the density of air is $1.3 kgm^{-3}$. The maximum power required from the wind farm is 0.75 MW. Each turbine has an efficiency of 30%.

17a. (i) Determine the diameter that will be required for the turbine blades to achieve the maximum power of 0.75 MW. *[8 marks]*

(ii) State **one** reason why, in practice, a diameter larger than your answer to (a)(i) is required.

(iii) Outline why the individual turbines should not be placed close to each other.

(iv) Some members of the community propose that the wind farm should be located at sea rather than on land. Evaluate this proposal.

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17b. Currently, a nearby coal-fired power station generates energy for the community. Less coal will be burnt at the power station if the wind farm is constructed. *[7 marks]*

(i) The energy density of coal is 35 MJ kg $^{-1}$. Estimate the minimum mass of coal that can be saved every hour when the wind farm is producing its full output.

(ii) One advantage of the reduction in coal consumption is that less carbon dioxide will be released into the atmosphere. State **one** other advantage and **one** disadvantage of constructing the wind farm.

(iii) Suggest the likely effect on the Earth's temperature of a reduction in the concentration of atmospheric greenhouse gases.

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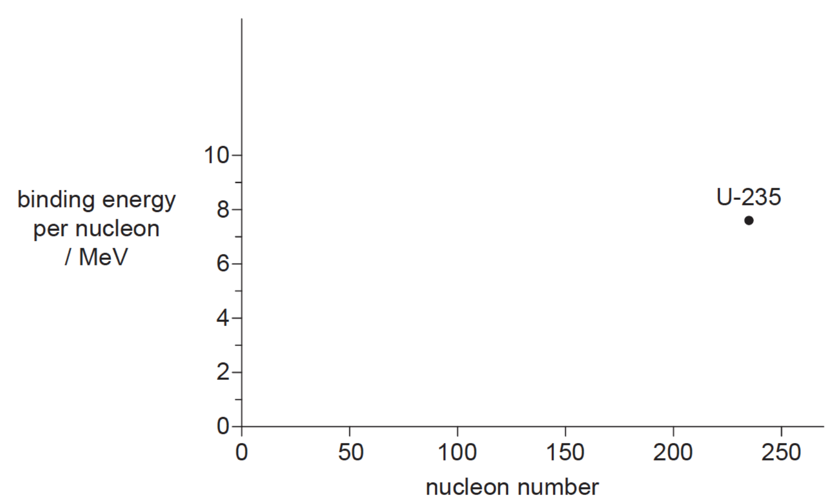
Part 2 Nuclear energy and radioactivity

The graph shows the variation of binding energy per nucleon with nucleon number. The position for uranium-235 (U-235) is shown.



17c. State what is meant by the binding energy of a nucleus. *[1 mark]*

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17d. (i) On the axes, sketch a graph showing the variation of nucleon number with the binding energy per nucleon. *[5 marks]*

(ii) Explain, with reference to your graph, why energy is released during fission of U-235.

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17e. U-235 $\left({}^{235}_{92}\mathrm{U}\right)$ can undergo alpha decay to form an isotope of thorium (Th). *[4 marks]*

(i) State the nuclear equation for this decay.

(ii) Define the term *radioactive half-life*.

(iii) A sample of rock contains a mass of 5.6 mg of U-235 at the present day. The half-life of U-235 is 7.0×10^8 years. Calculate the initial mass of the U-235 if the rock sample was formed 2.1×10^9 years ago.

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This question is about energy sources.

A small island is situated in the Arctic. The islanders require an electricity supply but have no fossil fuels on the island. It is suggested that wind generators should be used in combination with power stations using either oil or nuclear fuel.

18a. Suggest the conditions that would make use of wind generators in combination with either oil or nuclear fuel suitable for the islanders. *[3 marks]*

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18b. Conventional horizontal-axis wind generators have blades of length 4.7 m. The average wind speed on the island is 7.0 ms^{-1} and the average air density is 1.29 kg m^{-3}. *[5 marks]*

(i) Deduce the total energy, in GJ, generated by the wind generators in one year.

(ii) Explain why less energy can actually be generated by the wind generators than the value you deduced in (b)(i).

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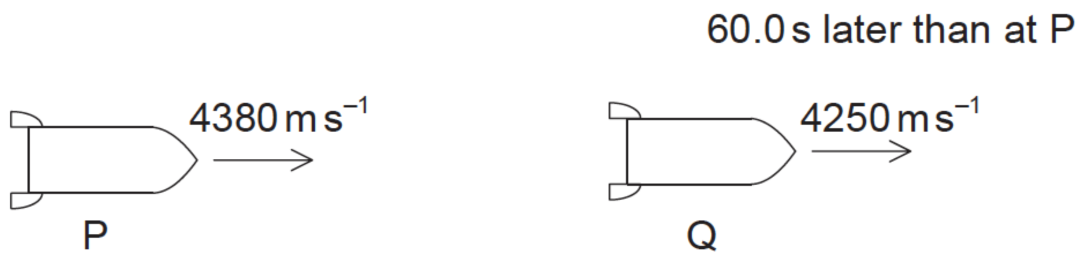
Part 2 Motion of a rocket

A rocket is moving away from a planet within the gravitational field of the planet. When the rocket is at position P a distance of 1.30×10^{7}m from the centre of the planet, the engine is switched off. At P, the speed of the rocket is 4.38×10^{3}ms^{-1}.



At a time of 60.0 s later, the rocket has reached position Q. The speed of the rocket at Q is 4.25×10^{3}ms^{-1}. Air resistance is negligible.

19a. Outline, with reference to the energy of the rocket, why the speed of the rocket is changing between P and Q. *[2 marks]*

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19b. Estimate the average gravitational field strength of the planet between P and Q. *[2 marks]*

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19c. A space station is in orbit at a distance *r* from the centre of the planet in (e)(i). A satellite is launched from the space station so as just to escape from the gravitational field of the planet. The launch takes place in the same direction as the velocity of the space station. Outline why the launch velocity relative to the space station can be less than your answer to (e)(i). *[1 mark]*

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